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# Municipal solid waste to energy generation: An approach for enhancing climate co-benefits in the urban areas of Bangladesh

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A B S T R A C T

Ever-growing scarcity of land resources around the world brands the waste to energy (WtE) strategy as a promising option for municipal solid waste (MSW) management. WtE conversion not only reduce the land pressure problem in urban areas, but also generate electricity and heat to supply to the surrounding urban areas. Moreover it also warrants climate benefits by avoiding fossil fuel based energy. The goal of this paper is to evaluate the MSW renewable energy potential and climate benefits through carbon reduction in Bangladesh using WtE strategies for urban area waste management. The study is conducted based on the waste generation of 7 major city corporation, 308 municipalities and 208 other urban areas in Bangladesh. Energy potential of different WtE strategy is assessed using standard energy conversion model and subsequent greenhouse gases (GHG) emissions models. GHG emission avoidance is also estimated based on coal based electricity displacement and avoidance from existing MSW management practices. Six different WtE scenarios are evaluated consisting of mixed MSW incineration and landfill gas (LFG) recovery systems. The total projected GHG emission observed within the range of 3.45–4.68 million MT $CO_{2eq}$ and 5.45–9.59 million MT $CO_{2eq}$ by 2030 and 2050, respectively under BAU scenario. The projected highest total renewable electricity generation potential from MSW in Bangladesh observed within the range of 4173.90–5645.30 GWh by 2030, and 6582.48-11579.12 GWh by 2050. Renewable electricity potential in Dhaka is highest (1399.56-712.86 GWh) followed by Chittagong (762.74–900.24 GWh) by 2030, with associated GHG avoidance of 1.18–1.44 and 0.64–0.76 million t $CO_{2eq}$, respectively. Scenario $A_1$ provides the highest economic gain with energy potential and net negative GHG emissions. The study proposes mixed MSW incineration as a potential source of renewable electricity to ensure climate friendly urban area management in Bangladesh.

## 1. Introduction

Around the world human society's endures race for modern urbanized life generating tremendous amount of municipal solid waste (MSW) – a key by-product of urban lifestyle. The fast urbanization rate resulting in mounting MSW generation [1,2]. A twofold increase of global MSW generation was observed for the period of 2000–2010. During 2010 global MSW generation was 1.3 billion MT and by 2025 it is projected to reach 2.2 billion MT and 4.2 billion MT by 2050 [2]. Such rapid rise of waste footprint from the urbanized system will certainly have a negative impact on sustainable living style as well as on the local environment (air, water, land) and human health, if not managed properly [3]. Rapid population growth, and the accompanied factors like fast industrialization for national economic growth, and urbanization causing severe MSW management problems in a number of cities in developing and under developed countries like China, India, Malaysia, Thailand and Bangladesh [4–7].

Significant environmental problems in Bangladesh due to improperly managed municipal solid waste (MSW) are already documented because of fast population growth and ongoing rapid industrialization [8–10]. A great influx of village workforce to cities of Bangladesh because of job availability and higher income opportunity causing tremendous expansion of urban boundary [11–13]. The two elements, i.e. population and economy growth should be constructively transformed, because they are the major drivers of sustainable waste management in Asia [5,14]. Sustainable MSW management around the world is based on four options such as- thermal treatment, biological treatment, landfilling with gas (LFG) recovery, and recycling [15]. Among them, thermal treatment, biological treatment, and LFG recovery are based on the theme of recovery, i.e., energy recovery option of MSW management hierarchy [16].

Waste-to-energy (WtE) strategy refers to any waste treatment process generating energy in the form of electricity, heat or transport fuels from a waste source. WtE is a very promising alternative energy

**Table 1**
Overview of major WtE technologies.

| WtE technology | Description | Conversion Efficiency (MWh/ton MSW) | Service Life (year) | Typical MSW input heating value (MJ/Kg) | Max Fuel Moisture (%) | Input | Products |
|---|---|---|---|---|---|---|---|
| Waste incineration | Mixed MSW incinerated in a boiler and equipped with CHP plant. Incineration temperatures is 1000–1200 °C. | 0.5[A] | 30[A] | 8–10.5[B] | 40–50[A] | Mixed MSW | Electricity and heat. |
| Pyrolysis | Thermochemical decomposition of organic fraction of MSW at low temperatures in presence of limited or in absence of oxygen. Operating temperatures is 200–300 °C. | 0.3[A] | 20[A] | | 10[A] | Sorted MSW | Liquid oil, Char, Gas |
| Gasification | Process of reacting the organic fraction of MSW at high temperatures with controlled amount of oxygen and steam to produce carbon monoxide, hydrogen and carbon dioxide. Operating temperatures is > 700 °C. | 0.9[A] | 20[A] | 16.5[B] | 40–50[A] | Sorted MSW | Electricity, $CH_4$, Hydrogen, Ethanol |
| Anaerobic digestion | Biological process of breakdown of organic fraction of MSW by a consortium of anaerobic microorganisms working synergistically in an oxygen poor environment. Most of the anaerobic digesters designed to operate in the temperature range of 30–35 °C. | 0.15[D] | 20[A] | 2.5[B] | Approx. 97[A] | Sorted MSW | Electricity, heat, LNG |
| LFG gas recovery | Landfill gas [1] is a saturated gas consisting of 50% $CH_4$ and 50% $CO_2$ by volume, along with some other trace contaminants. $CH_4$ is trapped to generate electricity. | 0.23[E] | 30 to 50[E] | – | 70–80[C] | Mixed or sorted MSW | Electricity, heat, LNG |

*Note:* .
A [56].
B [20].
C [57].
D [58].
E [5].

option for the future, because the projected 2.3 billion MT MSW is equivalent to 24.5 quadrillion Btu of energy. 10% of global annual electricity need can be satisfied with this amount of energy [17]. WtE identified as one of eight technologies likely to make a meaningful contribution to a future low-carbon energy system, by the World Economic Forum in its 2009 report, "Green Investing: Towards a Clean Energy Infrastructure" [18]. It is estimated that WtE option will treat at least 261 million tons of MSW per year to produce an estimated 283 terawatt hours (TWh) of electricity and heat by 2022 [17]. WtE strategy simultaneously provides a number of benefits like minimization of waste volume, a potential renewable energy (RE) source, and potential climate benefits through greenhouse gas (GHG) emissions avoidance from fossil fuel based energy sources. The most two common practice for WtE strategy is waste incineration and LFG recovery system [19], while the most economically feasible solutions reported for the future energy system are mixed waste incineration [20]. Table 1 gives a general overview of major WtE technologies.

Around the world WtE strategy for the management of MSW primarily based on mixed waste incineration has been implemented in a number of countries such as- Germany, Sweden, The Netherlands, Denmark, and the UK in Europe, USA and Canada in North America, and Japan, China, Korea, Indonesia and Malaysia in Asia [19,21–23]. Globally around 1600 WtE incineration plants are operating till 2013 in approximately 40 countries, while most of them located in Europe (472), Japan (100), the USA (86), Australia (74) [24]. In China, the WtE incineration plants which are either operational or under construction are expected to be over 300 by the end of 2015 [7,25], with an aim to build the world largest WtE incineration plant in Shenzhen [26].

In Bangladesh, sustainable MSW management is still a dilemma as reflected in Fig. 1, in spite of continuous government effort [8,9]. In Bangladesh, a number of studies have been conducted to report such dilemma covering a number of aspects such as-characterization and factor of the MSW generation [10,27–30], disposal status and management problems [8,31–36], peoples willingness to pay for different wastes management option [37,38], composting aspects [27,39,40], and recycling aspects [34,41]. A few studies have been conducted to estimate electricity generation potential [42–44]. Some recent study evaluated GHG footprint and the carbon flow of waste management option [78], economic analysis of WtE strategy in Chittagong [79], and renewable electricity assessment in two major city [80].

Economic and social development aiming to improved living standard in a society depends on energy availability [21,45]. Unfortunately, in Bangladesh, major portion of the energy consumed is based on fossil fuel, which are not sustainable [46]. Bangladesh is an energy deficit country, because energy and electricity generation from domestic supply is far below than the growing demand [47]. To overcome this energy deficit situation, Bangladesh government recently aims to reduce gas-based electricity generation and gradually shift to coal-fired power plant, which will certainly increase national carbon footprint [48–50]. According to the initial national communication energy sector contribution was 33.12% and waste sector contribution was 2.88% of national GHG emissions during 1994. This contribution increased to 38.89% and 14.85% respectively as per second national communication during 2005. It can be say that this share will definitely increase in future. However, Bangladesh recently committed to reduce 5% (voluntarily) and additional 15% (conditional) GHG emission from transport, energy and industry sector in her intended determined contribution (INDC). So, WtE strategy can offer Bangladesh a favorable option to reduce the national GHG footprint both from wastes and energy sectors. Bangladesh is an energy dependent country and an increase in the energy supply have a positive impact to the economic development [51–53]. Thus, WtE strategy for the management of MSW in Bangladesh can provide alternative and renewable energy source and climate benefits by avoiding significant GHG emissions by replacing the equivalent fossil fuels electricity. Moreover, deploying WtE strategy will help Bangladesh to move towards waste less resources recovery based society.

So, this study is conducted with the goal to assess the potential of WtE strategy for renewable energy production from MSW, and associated fossil fuel carbon avoidance in Bangladesh to explore the potential climate benefits. Two WtE technologies, such as-mixed waste incineration and LFG recovery are selected for the assessment of
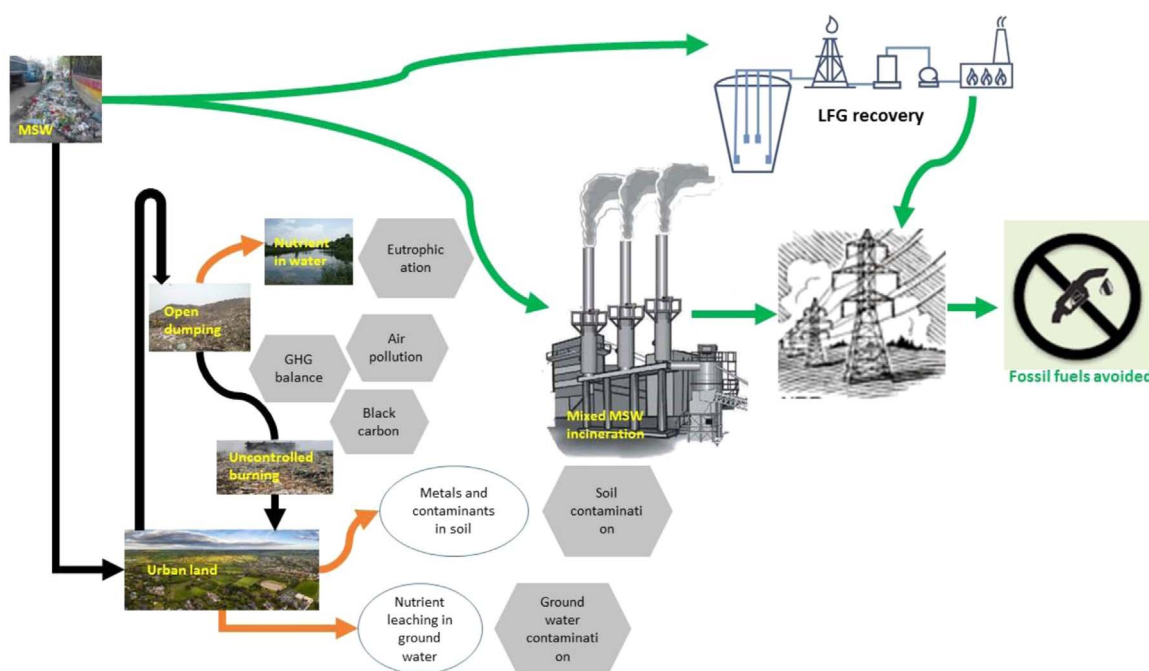


**Fig. 1.** MSW cascade illustrating the key role of WtE strategy for renewable electricity generation and possible climate benefits in Bangladesh. The figure shows the input of MSW, contrasting the intended flows from the urban areas (black arrows), the unintended flows as this pass down the cascade (orange arrows), the environmental concerns (ash boxes), and possible flows (green arrows) for renewable electricity generation and climate benefits. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

renewable energy generation and carbon reduction, because these two WtE option are the most preferable and mature technology practicing around the world. An overview of an existing MSW management context in Bangladesh and MSW stream characteristics is presented in Section 2. The adopted methodology of this study is then described in Section 3, and finally the results along with a sensitivity analysis are reported and discussed in Section 4. Section 5 concludes the study.

## 2. Existing MSW management

City corporation or municipalities under the ministry of local government and engineering department in each major cities or municipalities are responsible management of MSW in Bangladesh. For example Dhaka city corporation (DCC) was responsible for the collection, transportation and disposal of MSW in Dhaka city with 92 wards. But now, DCC is divided into DCC (North) with 36 wards and DCC with 56 wards and the collection, transportation and disposal of MSW in Dhaka city is also divided accordingly [54]. Similarly, Chittagong city corporation is responsible for the collection, transportation and disposal of MSW in Chittagong city with 41 wards [4]. All of the municipalities like Dhaka,Chittagong, Rajshahi, Khulna, Borishal, Sylhet, and Rangpur, as well as around 308 municipalities and 208 other urban centers disposed MSW in the open dump sites after collecting from household or large wastes container besides road [31,32,55]. The typical features of open dump sites of major city corporations are presented in Table 2. For example, in Dhaka all the wastes are sent for open dumping in Matuail and Amin Bazar dumping ground. Matuail dumping sites named as sanitary landfill with an aim to practice sanitary landfilling, but now open dumping is practiced here. Wastes from 55 ward in Dhaka city are dumped in Matuail dumping sites and wastes from 36 ward dumped in Amin Bazar open dumping ground. Similarly, in Chittagong, all the wastes currently dumped into Ananda Bazar, Kalurghat, and Arefinnagar open dumping sites, while Roufabad open dumping sites closed in 2014. Ananda Bazar dumping ground is the oldest open dumping sites in Chittagong and expected to close in 2020. In most of the city corporation household wastes are collected by the small human driven three wheel vans, and transported to the large waste bins located besides major roads. Such practice often creates odorous and public nuisance in the road as shown in Fig. 2.

Typical characterization of MSW in Bangladesh by different study is presented in Table 3. From the Table 3, it can be clearly states that the MSW in Bangladesh consists of mainly two fraction, such as-organic and inorganic components. MSW typically contains food waste, paper, textile, rubber, plastic, glass, metals and wood, whereas stones and ashes are the miscellaneous wastes. The major fraction (75%) of MSW in Bangladesh is food waste [29,32], whereas in China it is 50% [7], 40–60% in Malaysia [5,21], 20–30% in U.S. and European countries [43]. The relative contribution of the major cities, municipalities and other urban centers to the total wastes generation in 2015 is shown in Fig. 3, and Table 4 presents the calculation of total wastes generation.

## 3. Approach and methodology

### 3.1. Data collection

This study was conducted based on the primary data of Dhaka and Chittagong, and the other urban centers data are based on extensive literature survey. MSW projection model through Eqs. (1) and (2) were used to predict the future MSW (Section 3.2), Eqs. (6) and (7) were used to model the energy generation through MSW incineration plant (Section 3.4), and Eq. (8) was used to model the $CH_4$ emissions from landfill (Section 3.4). Eqs. (8) and (12) were used to model the GHG emission (Sections 3.6, 3.7 and 3.8). Different WtE option were analyzed under six different scenarios to find the optimum solution. To evaluate the effects of moisture content of MSW on the energy

**Table 2**
MSW disposal site and their salient features in Bangladesh.

| Waste dumping type | Salient features | Dhaka | | Chittagong | | | | Rajshahi[a] | Khulna[b] | Borishal | Sylhet |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Matuail | Amin Bazar | Ananda Bazar | Arefinnagar | Kalurghat | Roufabad | Nawdapara | Rajbandh | Gauashawr | Lalmatia |
| Open dumping | Area (hectares) | 40 | 20 | 2.023 | 29.5 | 7.28 | 2.83 | 6.48 | 10.12 | 2.23 | 3.2 |
| | Managing authority | DCC | CCC | RCC | KCC | BCC | SCC | | | | |
| | Condition | in operation | in operation | in operation | in operation | in operation | closed | in operation | in operation | in operation | in operation |
| | Land filling started | 2003 | 2007 | 1960 | 2011 | 2015 | 2001 | 2004 | 1995 | 2007 | – |
| | Closed/expected end of life | 2021 | 2023 | 2020 | 2017 | 2016 | 2014 | 2022 | – | – | – |
| | Height of MSW deposit (meter) | 7 | 6.4 | 8.7 | 6.5 | 6 | 8.6 | 4.2 | 4.3 | 4.01 | 4.5 |
| | Distance from the city (km) | 6 | 8 | 6 | 5 | 7 | 5 | 8 | 9 | 5 | 4 |
| | Average disposal per day (tons) | 2000 | 1200 | 350 | 671 | 722 | 950 | 280 | 270 | 42.68 | 74 |
| | Current CH4 status | No recovery | No recovery | No recovery | No recovery | No recovery | No recovery | No recovery | No recovery | No recovery | No recovery |
| | Ward covered | 55 | 36 | 21 | 20 | 21 | 28 | 15 | 31 | 30 | 27 |

**Fig. 2.** Existing MSW management in the urban areas of Bangladesh.

potential and GHG emissions a sensitivity analysis was performed. The methodological framework of the study is presented in Fig. 4.

### 3.2. Projected future MSW generation

Future MSW generation was projected using historical trend; and compound annual growth rate (CAGR), gross annual product (GAP) and income spending approach. A brief sketch about these two approach is given here:

(i) Historical trend: Census data [60] in the respective city was used to calculate annual growth rate of population, and average growth rate in the per capita waste generation was calculated from historical waste generation 2001−2015) for Dhaka and Chittagong. Historical waste generation data for other cities and municipalities was not available, that is why per capita waste generation average growth rate reported for Bangladesh (0.21%) is used for other cities and municipalities [8−10]. Projected waste generation was calculated

using the Eq. (1).

$$PWG = (PBY + PBY \times AGP) \times (PCWB + PCWB \times AGW)$$
$$\times 365 \times 1/1000 \tag{1}$$

Here, PWG=Projected wastes generation in a year (tons).

PBY = Population in baseline year.
AGP = Annual growth rate of population.
PCWB = Per capita wastes generation in baseline year (kg/cap/day).
AGW = Average growth rate in the per capita waste generation.

(i) Compound annual growth rate (CAGR), gross annual product (GAP) and income spending approach: In the respective city using census data [60], compound annual growth rate (CAGR) of population was calculated at first. Gross Annual Product (GAP) growth rate of Bangladesh was assumed as 4%, while also assume, 70% of income going into consumption in Bangladesh [31]. The waste generation growth factor = 4% ×70% = 0.028. Lastly, using

**Table 3**
Typical MSW composition in Bangladesh.

| Material | Dhaka | | | | Chittagong | | | | Rajshahi | Khulna | Barisal | Sylhet | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | A | E | F | G | A | A | A | A | A |
| Food/organic | 68.3 | 84.37 | 80 | 59.91 | 73.7 | 61 | 72 | 62 | 71.1 | 78.9 | 81.1 | 73.5 | 74.4 |
| Plastic | 4.3 | 1.74 | 4.5 | – | 2.8 | 3 | 3 | 2 | 4.0 | 3.1 | 3.5 | 3.5 | 3.5 |
| Paper | 10.7 | 5.68 | 10 | 11.21 | 10 | 9 | 5 | 3 | 8.9 | 9.5 | 7.2 | 8.6 | 9.1 |
| Textile | – | 1.83 | – | – | – | 8 | 3 | 1 | – | – | – | – | – |
| Wood | – | – | – | – | – | – | 2 | 3 | – | – | – | – | – |
| Grass/Garden wastes | – | – | – | 8.76 | – | 3 | – | – | – | – | – | – | – |
| Rubber | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Glass | 0.7 | 6.38 | 1.7 | – | 0.9 | 3 | 3 | 5 | 1.1 | 0.5 | 0.5 | 0.7 | 0.8 |
| Aluminium/metals | 2.0 | – | 1 | 0.15 | 2.2 | 2 | 4 | 9 | 1.1 | 1.1 | 1.2 | 1.1 | 1.5 |
| Textile and wood | 2.2 | – | – | – | 2.1 | – | 3 | – | 1.9 | 1.3 | 1.9 | 2.1 | 1.9 |
| Leather and rubber | 1.4 | – | – | 17.67 | 1 | – | – | – | 1.1 | 0.5 | 0.1 | 0.6 | 0.8 |
| Pack | – | – | | | | | 6 | 9 | – | – | – | – | |
| Stone/Rocks | – | – | – | 2.30 | – | 5 | 2 | 6 | – | – | – | – | |
| Others/Miscellaneous | 10.4 | – | 3.5 | – | 7.4 | 6 | – | – | 10.8 | 5.1 | 4.5 | 9.9 | 8.0 |

*Note*: .
[A] Same MSW character of Dhaka and Chittagong city is reported in these studies [27,41,43,59]. [B] [44], [C] [30], [D] [42].
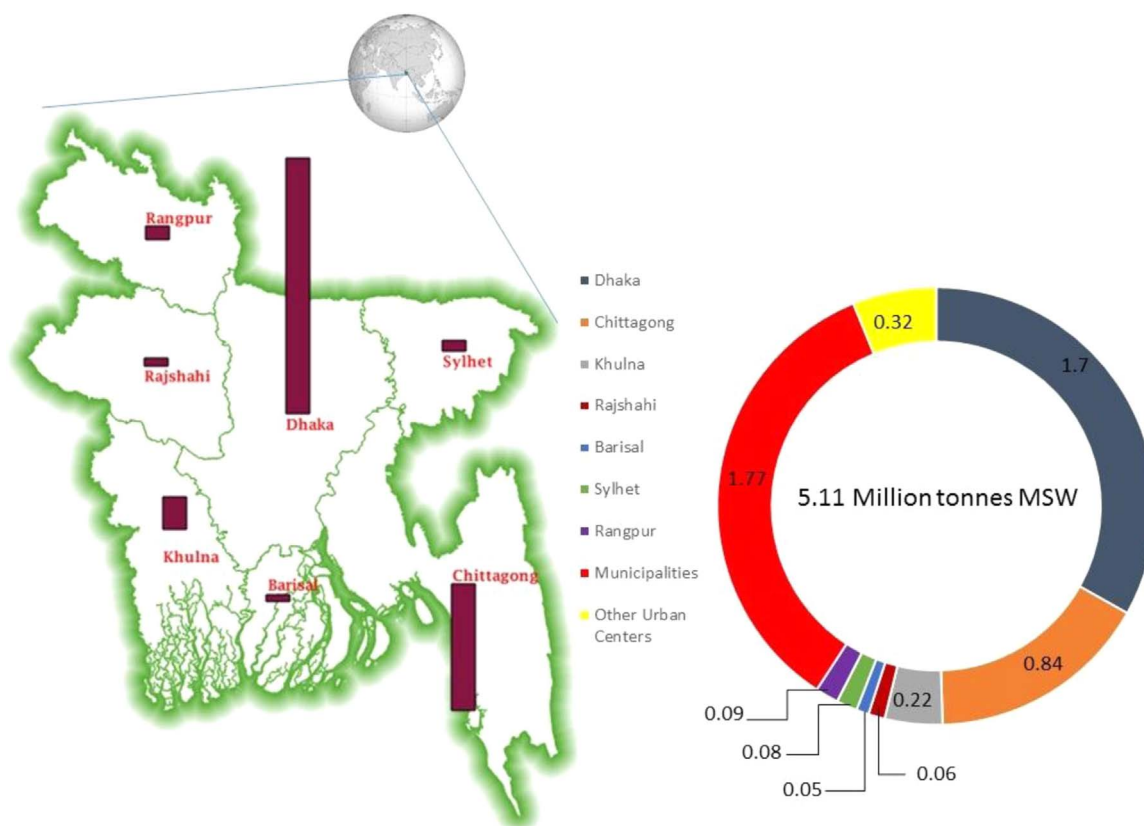[E] [32], [F] [28], [G] [29].

**Fig. 3.** Location map of the major cities with contribution to the total generated MSW of Bangladesh during 2015.

**Table 4**
Total estimated urban waste generation in Bangladesh during 2015.

| Location | Number of city | Waste generation rate (Kg/ capita/day) | Population in 2015 (million) | Waste generation (million tonnes/year) |
|---|---|---|---|---|
| Dhaka[a] | 1 | 0.600 | 7.728 | 1.70 |
| Chittagong[a] | 1 | 0.610 | 3.76 | 0.84 |
| Khulna[b] | 1 | 0.397 | 1.5 | 0.22 |
| Rajshahi[b] | 1 | 0.378 | 0.45 | 0.06 |
| Barisal[b] | 1 | 0.325 | 0.40 | 0.05 |
| Sylhet[b] | 1 | 0.430 | 0.50 | 0.08 |
| Rangpur[b] | 1 | 0.239 | 1.0 | 0.09 |
| Municipalities[c] | 308 | 0.25 | 19.36 | 1.77 |
| Other Urban Centers[c] | 208 | 0.15 | 5.76 | 0.32 |
| Total | 523 | | 39.488 | 5.11 |

*Note*: .
[a] From the field study.
[b] [43].
[c] [59].

the Eq. (2), projected waste generation was calculated.

$$PWG = (PBY + PBY \times CAGR) \times (PCWB + PCWB \times WGG) \times 365 \times 1/1000 \qquad (2)$$

Here, PWG = Projected wastes generation in a year (tons).

PBY = Population in baseline year.
CAGR = Compound annual growth rate of population.
PCWB = Per capita wastes generation in baseline year (kg/cap/day).
WGG = Waste generation growth factor.

### 3.3. MSW physical and chemical properties

Physical characteristics of waste stream of an urban area, like-waste composition fraction on wet weight basis, and dry weight fraction as well as moisture content are important factor to determine energy recovery alternative. Similarly, chemical properties, such as-molecular composition in relation to organic carbon ($C_{org}$), inorganic carbon ($C_{iorg}$), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), and ash also influence this decision [19]. Standard molecular composition of different solid wastes category based on dry weight fraction of MSW was used in this study [61]. Moisture content (%) and dry weight fraction (%) of MSW was calculated using the Eqs. (3) and (4).

$$X = \left( \frac{A - B}{A} \right) \times 100 \qquad (3)$$

In Eq. (3), X = moisture fraction of MSW (%), A = initial weight of sample an individual class, and B = weight of an individual class after drying.

$$X = Y \times (100 - Z) \qquad (4)$$

In Eq. (4), X = dry weight fraction of MSW (%), Y = wet weight fraction of MSW (%), and Z = moisture content (%). Table 5 presents the Physical and chemical properties of MSW considered in this study.

### 3.4. Energy from MSW incineration

Energy content of MSW highly influence the waste combustion processes in an incinerator to generate the electricity. For generation of electricity by combusting MSW, unsegregated wastes feed stock combusted in a furnace or boiler, under high temperature (980–1090 ℃) conditions with excess oxygen. MSW feed stock is converted into heat, flue gases and particulates, and incinerator bottom ash. The heat is used to produce steam and based on the Rankine cycle principle in a steam turbine electricity is generated [19,61,62]. Under ideal
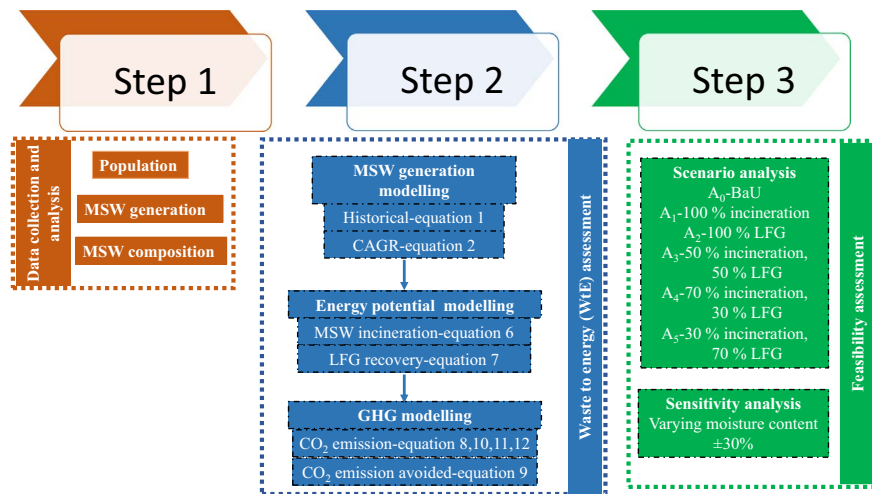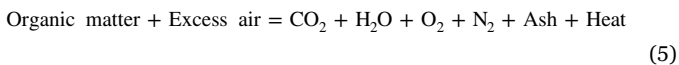
**Fig. 4.** Methodological approach of the study.

situation MSW combustion processes chemical reaction is represented using the Eq. (5) [19]

$$\text{Organic matter} + \text{Excess air} = CO_2 + H_2O + O_2 + N_2 + \text{Ash} + \text{Heat} \tag{5}$$

The energy content of MSW is usually expressed by its lower heating value (LHV). In this study, the approximate LHV of MSW computed by ultimate analysis. Under the ultimate analysis, LHV of MSW is estimated using the mathematical correlation of the modified Dulong's equation, as shown in Eq. (6) [19,61] [62].

$$\text{Energy content (LHV in kcal/kg)} = \left\{ 7831X_{C_{org}} + 35932(X_{H_2} - X_{O_2}/18) \right.$$
$$+ 2212X_S + 354X_{C_{iorg}} + 1187X_{O_2}$$
$$\left. + 578X_{N_2} \right\} \times (100 - MC) \tag{6}$$

The calculated energy (kcal/kg) of Eq. (6) is converted to KJ/Kg using 1 Kcal= 4.184 KJ. The values of the variables in Eq. (6), such as- $C_{org}$, $C_{iorg}$, MC (moisture content), etc. presented in Table 5.

### 3.5. $CH_4$ generation for LFG recovery

Estimation of methane emission from solid waste disposal sites (SWDS) was done using a simple and straightforward method called the Intergovernmental Panel on Climate Change (IPCC) methodology [63]. IPCC method estimate methane emission from SWDS using the following Eq. (7).

$$CH_4 \text{emission}(tCH_4/\text{year}) = (MSW \times MSWF \times MCF \times DOC \times DOCF$$
$$\times FM \times X - RM)(1 - OF) \tag{7}$$

In Eq. (8), MSW = total waste generation (t/year); MSWF = waste fraction disposed to SWDS; X = 16/12-a conversion factor for converting C to $CH_4$. Table 6 presents several coefficients involved to adopt the IPCC model to estimate the $CH_4$ emission for this study, and related justification. Table 7 presents several WtE analysis parameters.

### 3.6. GHG emissions incineration plant

As represented in Eq. (8), MSW combustion principally converts chemical energy stored into it, to thermal energy through the combustion processes at high temperatures of 980–1090 °C [62]. Due to the combustion of MSW in wastes incineration plant, though carbon is emitted, it will usually avoids the use of fossil fuels based electricity and the release of $CH_4$ from open dumping site in Bangladesh contexts. This type of WtE project, can also account for carbon credit [19,65]. In this study, $CO_2$ emissions from waste incineration under different scenario analysis is estimated using the Eq. (8).

$$CO_2 \text{ emissions from WtE project (t } CO_2/\text{t MSW)}$$
$$= \sum_j (WF_j Ci_{org_j} \times OF_j) \times Z \tag{8}$$

In the Eq. (10), $WF_j$ = Dry weight fraction of waste component j; $C_{iorgj}$ = anthropogenic carbon fraction of component j; $OF_j$ = oxidation factor, with the default value of 1 for MSW; Z = C to $CO_2$ conversion factor, with the value of 44/12; and j = component of MSW incinerated.

**Table 5**
Physical and chemical properties of MSW considered in this study.

| | | Food wastes | Plastic | Paper | Grass & straw | Glass & Ceramic | Metals | Textiles | Others |
|---|---|---|---|---|---|---|---|---|---|
| **Physical Properties**[a] | Wet weight fraction (%) | 80 | 2 | 8 | 2 | 1 | 1 | – | 6 |
| | Moisture content (%) | 72.34 | 0.53 | 3.2 | 38.21 | 0 | 0 | – | 8.67 |
| | Dry weight fraction (%) | 22.13 | 1.99 | 7.74 | 1.24 | 1.00 | 1.00 | – | 5.48 |
| **Chemical Properties**[b] | Organic carbon ($C_{org, \%}$) | 48.00 | 0 | 43.50 | 47.8 | 0 | 0 | 55.00 | 24.3 |
| | Inorganic carbon ($C_{iorg, \%}$) | 0 | 60.00 | 0 | 0 | 0.50 | 4.50 | 0 | 0 |
| | Ash (%) | 5.00 | 10.00 | 6.00 | 4.50 | 98.90 | 0.46 | 2.50 | 68 |
| | Sulphur (S, %, %), | 2.60 | 0.00 | 0.30 | 3.40 | 0.10 | 0 | 90.50 | 0.2 |
| | Nitrogen (N, %), | 0.40 | 0.10 | 0.20 | 0.30 | 0.00 | 0 | 0.10 | 0.5 |
| | Oxygen (O, %), | 37.60 | 7.20 | 44.00 | 38.00 | 0.40 | 4.30 | 31.20 | 4 |
| | Hydrogen (H, %) | 6.40 | 22.80 | 6.00 | 6.00 | 0.10 | 0.60 | 6.60 | 3 |

*Note*: .
[a] From field study.
[b] Standard molecular composition of MSW [61].

**Table 6**
Parameters adopted for IPCC default method in this study.

| Parameter | Value | Justification |
|---|---|---|
| MSWF | 1 | All of the total MSW generated in Bangladesh is sent to the open dumping SWDS [31,32,55]. |
| MCF | 0.8 | The MCF coefficient for different types of SWDS. For properly managed sanitary landfills, MCF = 1; for uncategorized SWDS = 0.6; for open dump with > 5 m waste height = 0.8; and for open dump with < 5 m waste height = 0.4 [21,63,64]. |
| DOC | 0.158 | According to IPCC suggested methodology, DOC ranges from 0.08 to 0.21 and was estimated using the equation DOC = 0.4P + 0.15K + 0.3W. Here, P = fraction of papers in MSW, K = fraction of kitchen/food wastes in MSW and W = fraction of straw in MSW. |
| DOCF | 0.77 | Again, the DOCF is needed because the biodegradation of DOC does not occur completely over a long period, so a default value 0.77 was considered [21,57]. |
| FM | 0.5 | IPCC default methane proportion in LFG is 0.50 [63] |
| RM | 0 | Since, no methane recovery takes place now. |
| OF | 0 | IPCC default value [63] |

**Table 7**
WtE analysis parameter adopted under for this study.

| Parameter | Value |
|---|---|
| ***MSW incineration*** | |
| LHV of MSW | 9850 MJ/t MSW |
| Heat recovery efficiency | 80% |
| Electricity generation rate | 1 MWh/15.65 GJ |
| Operating time | 24 h |
| ***Landfill*** | |
| CH$_4$ volume conversion factor | 667 m$^3$ / ton of CH$_4$ |
| Calorific value of CH$_4$ | 17 MJ/m$^3$ |
| Electricity generation factor | 0.2775 KWh/MJ |
| ***Environmental and Economic factor*** | |
| CO$_2$ emission factor for electricity | 1.001 kg CO$_2$/KWh electricity |
| Carbon credit revenue | $ 15.2/ ton of CO$_2$ |
| Electricity sales revenue | $ 0.13/KWh of electricity consumed at the residential sector |

### 3.7. Environmental benefits

This study quantified the environmental benefits of using MSW for WtE projects and LFG from SWDS by equivalent CO$_2$ avoided from electricity production from coal. Bangladesh now is establishing all the coal based power plant to generate electricity and to ensure constant supply of electricity in future [48]. Hence, electricity generated using MSW under different scenario using waste incineration plant and LFG recovery, is assumed to replace electricity generated from coal and so, CO$_2$ emission avoidance is computed using the Eq. (9).

$$CO_2 \text{ avoidance } (t\ CO_2) = EP_{MSW} \times CF_{EC} \qquad (9)$$

In Eq. (11), $EP_{MSW}$ = electricity production from MSW using waste incineration plant or LFG recovery, and $CF_{EC}$ = carbon emission factor of per KWh electricity production from coal. Carbon emission factor of 1.001 kg CO$_2$/KWh was considered in this study [66].

### 3.8. GHGs emissions from existing practice

The existing practice in most of the urban areas in Bangladesh is open dumping and burning of the wastes. To estimate the GHG missions of the existing practice in Bangladesh Eq. (10) was used [63].

$$CO_{2\,Emissions}(t\ CO_2) = UW \times \sum (WFj \times DMj \times CFj \times FCFj \times OFj) \times Z \qquad (10)$$

Here, UW represents total amount of urban waste as wet weight open-burned; WF represents fraction of wastes component; j represents waste types in the wastes stream; DM represents dry matter content of the component j; CF represents fraction of carbon in the dry matter of component j; FCFj represents fraction of fossil carbon in the total carbon of component j; OFj represents oxidation factor with the default value of 1 for wastes; Z = 44/12-a conversion factor for converting C to CO$_2$.

Since, a large fraction of carbon in the waste is not oxidized during open burning, CH$_4$ emissions should be considered for open burning. Eq. (11) was used to estimate the CH$_4$ emissions of the existing practice in Bangladesh [63].

$$CH_{4\,Emissions}(t\ CH_4) = UW \times EF_{CH4} \qquad (11)$$

Here, UW represents total amount of urban waste open-burned; $EF_{CH4}$ represents default CH$_4$ emission factor 6.5 kg per ton of wastes burned by IPCC [63].

Eq. (12) was used to estimate the N$_2$O emissions of the existing practice in Bangladesh [63].

$$N_2O_{Emissions}(t\ N_20) = UW \times EF_{N_2O} \qquad (12)$$

Here, UW represents total amount of urban waste open-burned; $EF_{N2O}$ represents default N$_2$O emission factor 0.15 kg per ton of wastes burned by IPCC [63].

## 4. Results and discussion

### 4.1. Projected MSW and GHG emissions

Fig. 5 presents the waste generation projected with historical trend approach (upper panel), and CAGR, GAP and income spending approach (lower panel). The highest projected waste generation is observed for Dhaka city followed by Chittagong city. The estimated waste generation was 1.7 million MT in 2015, and expected to increase within a range of 2.78–3.40 million MT in Dhaka city by 2030, and within a range of 4.47–6.6 million MT by 2050. The increase of waste generation in Chittagong city is observed within the range of 1.51–1.79 million MT by 2030, and 2.59–3.61 million MT by 2050. While, in all the municipalities the combined projected waste generation is higher than the Dhaka city alone within the range of 2.77–4.13 million MT by 2030, and 4.18–8.77 million MT by 2050. Approximately 30.7–34.0%, 16.21–18.31%, 33.94–37.40% of total projected waste generation in Bangladesh will be from Dhaka, Chittagong, and all the municipalities, respectively by 2030. While, this share is expected to be 29.2–34.71%, 15.93–20.1%, and 32.45–38.70%, respectively by 2050.

The estimated total GHG emission during 2015 under the existing MSW management practice is 2.1278 million MT CO$_{2eq}$, of which highest contribution is from Dhaka (0.7039 million MT CO$_{2eq}$) followed by Chittagong (0.3491 million MT CO$_{2eq}$) in terms of individual city contribution (Fig. 6). While, GHG emissions from 308 municipalities is 0.7375 million MT CO$_{2eq}$ and from 208 other urban centers is 0.1318 million MT CO$_{2eq}$. The projected total GHG emissions is expected to reach within the range of 5.4522–9.5909 million MT CO$_{2eq}$ by 2050 if the existing management practice continues, similarly with highest contribution from Dhaka city (1.8647–2.7525 million MT CO$_{2eq}$), followed by Chittagong city (1.0797–1.5043 million MT CO$_{2eq}$).
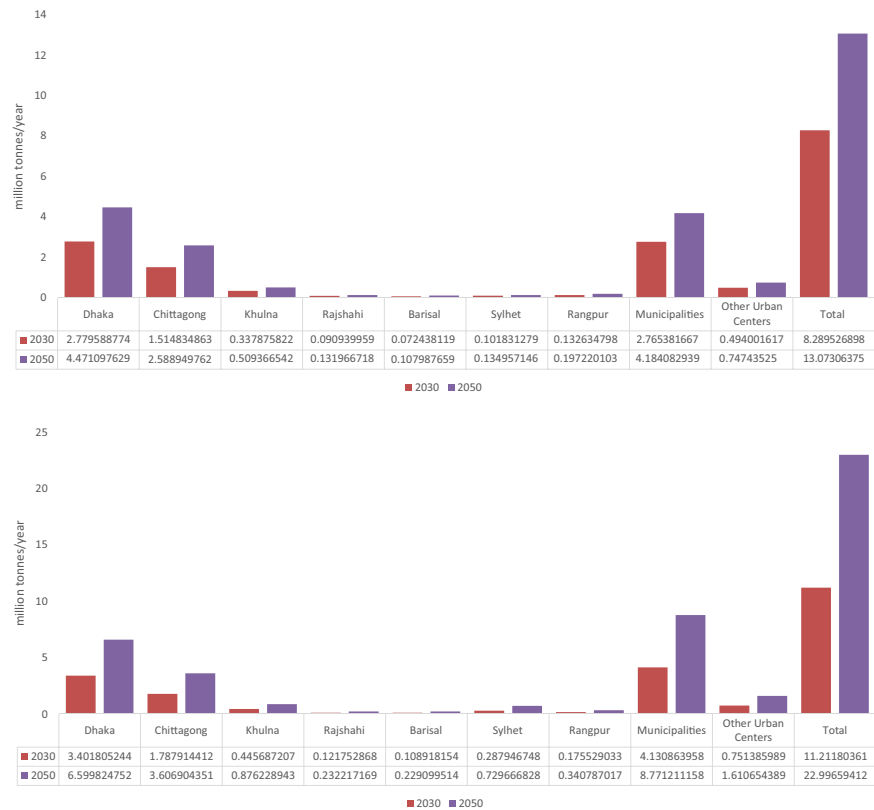
**Fig. 5.** Projected waste generation with historical trend approach (upper panel), and CAGR, GAP and income spending approach (lower panel) in the major municipalities and urban areas in Bangladesh.

### 4.2. Potential WtE and GHG avoidance

The LHV of MSW for incineration is calculated using Eq. (6), which is 2353.762 kcal/kg equivalent to 9.85 MJ/kg. Heat recovery efficiency for an MSW incineration plant is reported as 80–90% [19,67–69]. In this study, heat recovery efficiency for MSW incineration plant in Dhaka and Chittagong city assumed as 80%.

Electricity generation rate of the incineration process using steam turbine is taken as 1 MWh/15.65 GJ heat [19]. $CO_2$ emissions due to the incineration of MSW in Dhaka and Chittagong city will be 0.046 t CO2/t MSW, and 0.116 t CO2/t MSW, respectively based on Eq. (10). For landfill, generated $CH_4$ assumed to have a density of 0.667 kg/m$^3$, LHV of $CH_4$ 17 MJ/m$^3$, and electricity generation factor 0.2775 KWh/MJ [19,21].



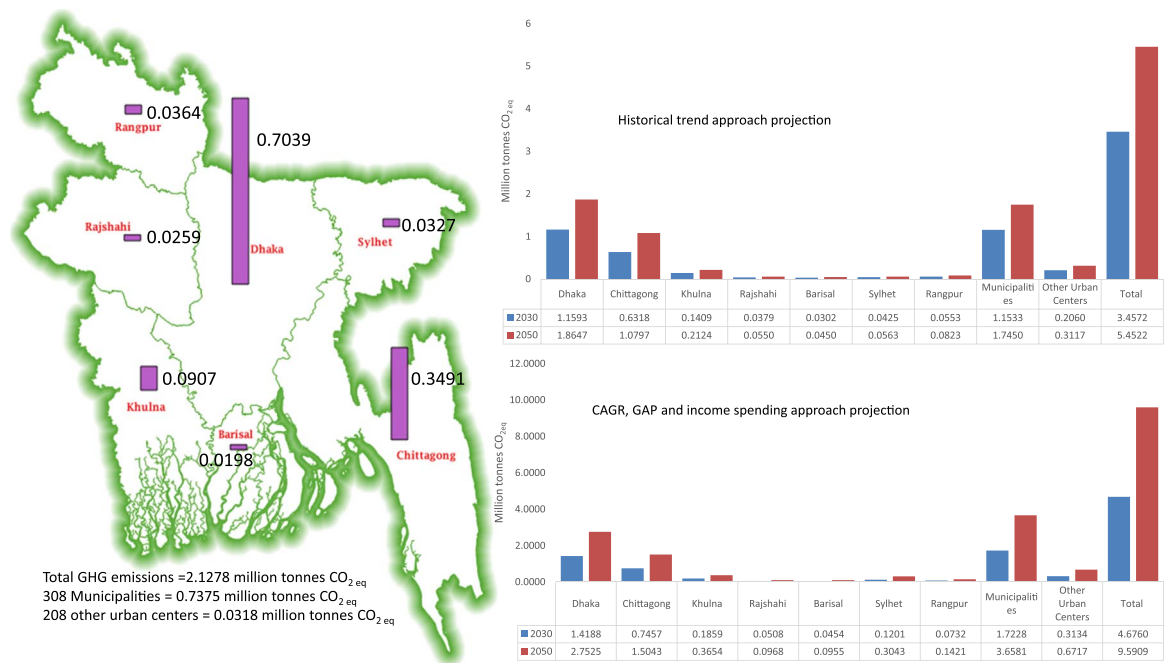**Fig. 6.** GHG emissions during 2015 (left panel) and projected GHG emissions (right panel) under existing MSW management practice.

Electricity generation potential from MSW incineration

| | Dhaka | Chittagong | Khulna | Rajshahi | Barisal | Sylhet | Rangpur | Municipalities | Other Urban Centers |
|---|---|---|---|---|---|---|---|---|---|
| Hist-2030 | 1399.56 | 762.74 | 170.13 | 45.79 | 36.47 | 51.27 | 66.78 | 1392.41 | 248.74 |
| Hist-2050 | 2251.26 | 1303.57 | 256.47 | 66.45 | 54.37 | 67.95 | 99.30 | 2106.75 | 376.34 |
| CAGR-2030 | 1712.86 | 900.24 | 224.41 | 61.30 | 54.84 | 144.99 | 88.38 | 2079.95 | 378.33 |
| CAGR-2050 | 3323.11 | 1816.13 | 441.19 | 116.92 | 115.35 | 367.40 | 171.59 | 4416.43 | 810.99 |

GHG avoidance potential in million tonnes $CO_{2eq}$ from MSW incineration

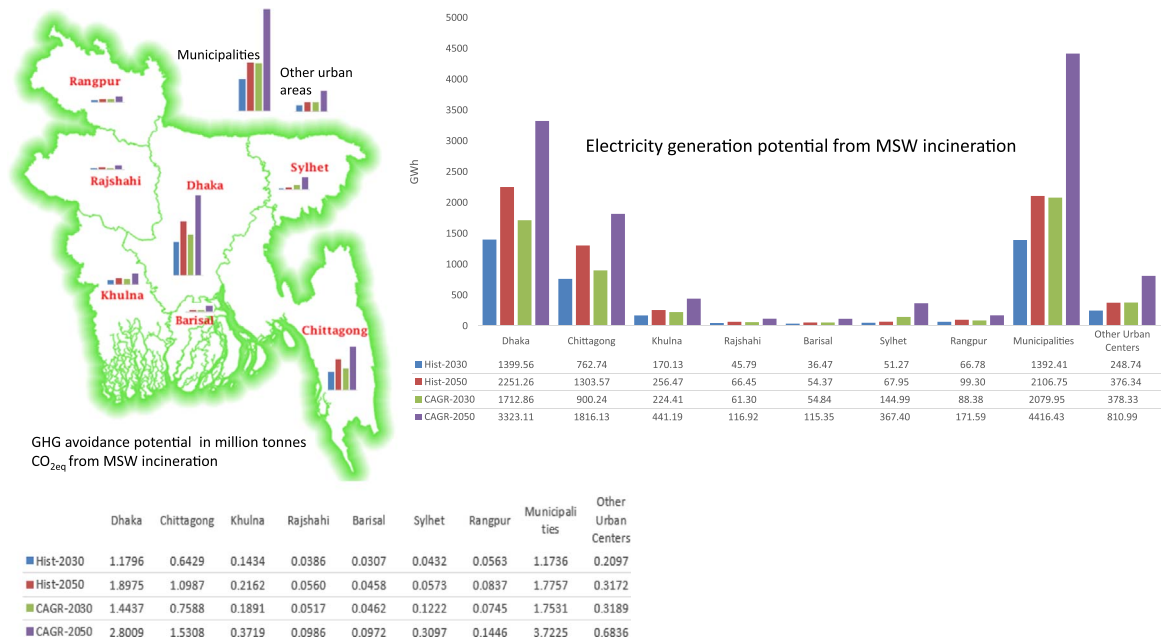| | Dhaka | Chittagong | Khulna | Rajshahi | Barisal | Sylhet | Rangpur | Municipalities | Other Urban Centers |
|---|---|---|---|---|---|---|---|---|---|
| Hist-2030 | 1.1796 | 0.6429 | 0.1434 | 0.0386 | 0.0307 | 0.0432 | 0.0563 | 1.1736 | 0.2097 |
| Hist-2050 | 1.8975 | 1.0987 | 0.2162 | 0.0560 | 0.0458 | 0.0573 | 0.0837 | 1.7757 | 0.3172 |
| CAGR-2030 | 1.4437 | 0.7588 | 0.1891 | 0.0517 | 0.0462 | 0.1222 | 0.0745 | 1.7531 | 0.3189 |
| CAGR-2050 | 2.8009 | 1.5308 | 0.3719 | 0.0986 | 0.0972 | 0.3097 | 0.1446 | 3.7225 | 0.6836 |

**Fig. 7.** WtE assessments in terms of electricity generation potential from MSW incineration and associated climate benefits in terms of GHG emission avoidance.

Figs. 7 and 8 presents the energy potential through electricity generation from MSW incineration and LFG recovery. As shown in Fig. 7, the electricity generation from incinerated MSW is estimated to be highest in Dhaka (within a range of 1399.56–1712.86 GWh) followed by Chittagong (within a range of 762.74–900.24 GWh) by 2030, with associated GHG avoidance of 1.18–1.44 and 0.64–0.76 million tonnes $CO_{2eq}$ respectively. This is electricity generation potential is expected to reach 2251.26–3323.11 GWh and 1303.57–1816.13 GWh, respectively by 2050. Renewable electricity generation potential from 308 municipalities is almost similar like Dhaka under the historical waste generation projection approach, while it is higher under waste generation projection based on CAGR and income spending approach.

Fig. 8 presents the renewable electricity generation potential and associated GHG emissions avoidance from LFG recovery. MSW incineration has a higher electricity generation but less GHG emissions

reduction potential compared to LFG recovery. This is because MSW incineration GHG avoidance represents net emissions (GHG avoidance less MSW incineration plant emissions), while LFG recovery has no system emissions.

### 4.3. Costs and revenue analysis

The WtE analysis reveals that, highest energy recovery potential from MSW in terms of individual city is in Dhaka and Chittagong city. Moreover, past MSW generation data (2001–2015) of these two city is also available. So, estimated costs and revenue analysis is performed only for this two city. The design capacity of incineration plant to generate electricity assumed as 1200 t/day with a life time of 35 years. Capital costs of incineration plant to generate electricity assumed as $36 per ton MSW per day [70], and operation and maintenance costs as $60 per ton of MSW [71]. On the other hand, landfill with LFG gas
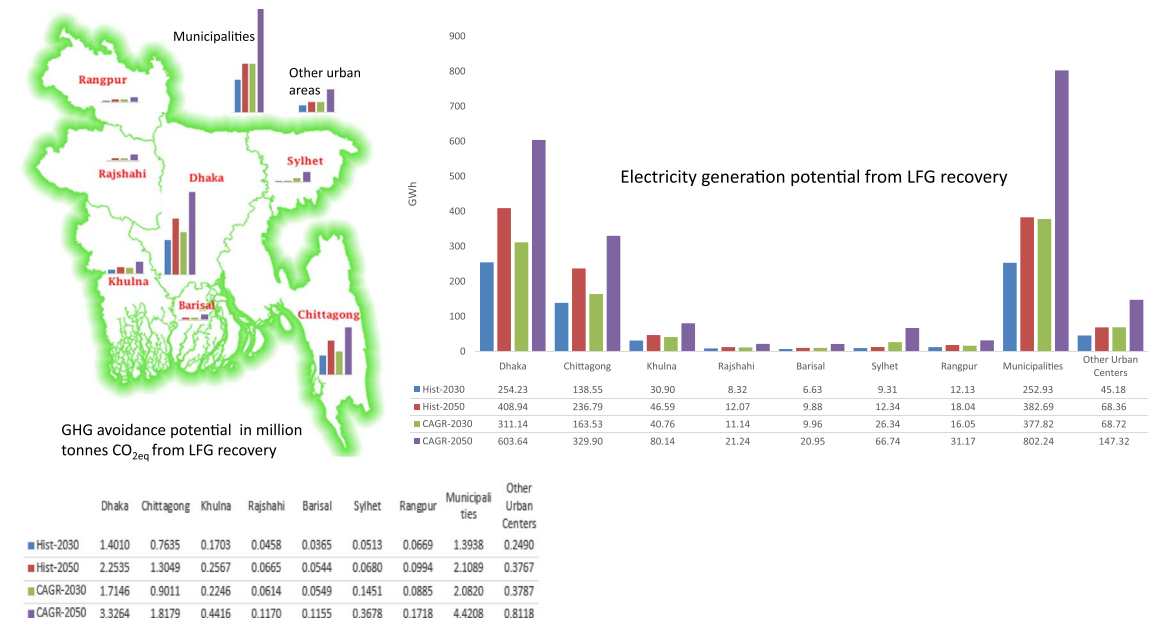


Electricity generation potential from LFG recovery

| | Dhaka | Chittagong | Khulna | Rajshahi | Barisal | Sylhet | Rangpur | Municipalities | Other Urban Centers |
|---|---|---|---|---|---|---|---|---|---|
| Hist-2030 | 254.23 | 138.55 | 30.90 | 8.32 | 6.63 | 9.31 | 12.13 | 252.93 | 45.18 |
| Hist-2050 | 408.94 | 236.79 | 46.59 | 12.07 | 9.88 | 12.34 | 18.04 | 382.69 | 68.36 |
| CAGR-2030 | 311.14 | 163.53 | 40.76 | 11.14 | 9.96 | 26.34 | 16.05 | 377.82 | 68.72 |
| CAGR-2050 | 603.64 | 329.90 | 80.14 | 21.24 | 20.95 | 66.74 | 31.17 | 802.24 | 147.32 |

GHG avoidance potential in million tonnes $CO_{2eq}$ from LFG recovery

| | Dhaka | Chittagong | Khulna | Rajshahi | Barisal | Sylhet | Rangpur | Municipalities | Other Urban Centers |
|---|---|---|---|---|---|---|---|---|---|
| Hist-2030 | 1.4010 | 0.7635 | 0.1703 | 0.0458 | 0.0365 | 0.0513 | 0.0669 | 1.3938 | 0.2490 |
| Hist-2050 | 2.2535 | 1.3049 | 0.2567 | 0.0665 | 0.0544 | 0.0680 | 0.0994 | 2.1089 | 0.3767 |
| CAGR-2030 | 1.7146 | 0.9011 | 0.2246 | 0.0614 | 0.0549 | 0.1451 | 0.0885 | 2.0820 | 0.3787 |
| CAGR-2050 | 3.3264 | 1.8179 | 0.4416 | 0.1170 | 0.1155 | 0.3678 | 0.1718 | 4.4208 | 0.8118 |

**Fig. 8.** WtE assessments in terms of electricity generation potential from LFG recovery and associated climate benefits in terms of GHG emission avoidance.
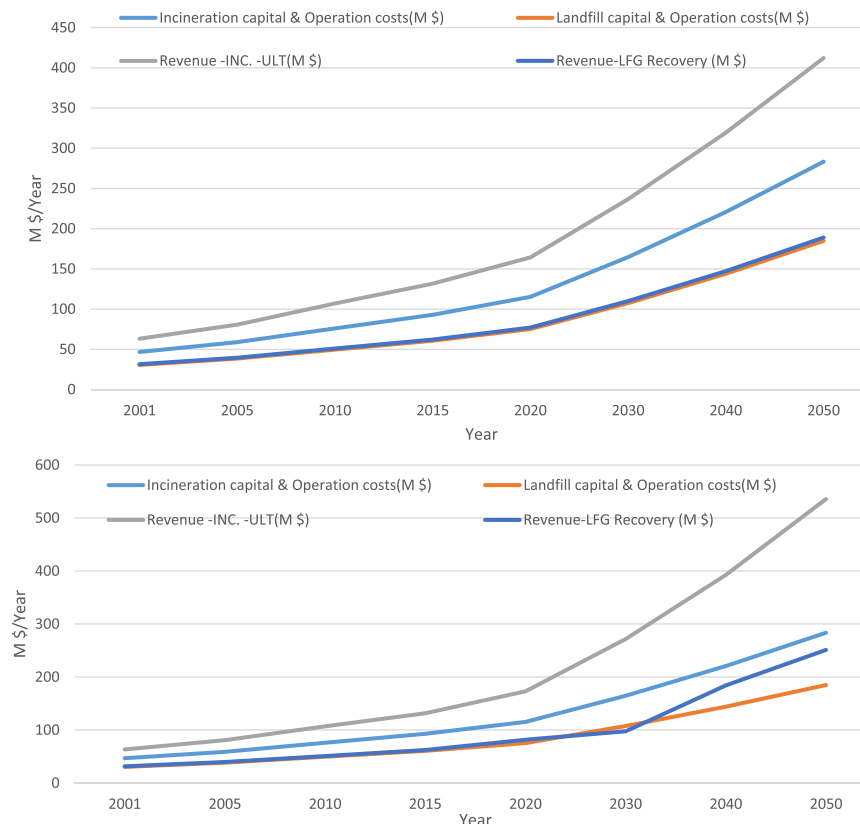
**Fig. 9.** Economic analysis (actual and projected) for LFG recovery system and waste incineration in Dhaka and Chittagong from year 2000 to year 2050. Carbon credit and electricity sales summed as revenue. Upper panel represent the projection using historical MSW generation rate and lower panel represent the projection using CAGR approach.

recovery system assumed to have a capacity of greater than 1000 t mixed MSW/day for a period of 35 years. Capital costs of landfill with LFG gas recovery system in Dhaka and Chittagong city assumed as $14 per ton MSW per day, and operation and maintenance costs as $10 per ton of MSW [71]. Carbon credit revenue assumed as $15.2 per ton of $CO_2$ [72]. Electricity sales revenue assumed as $0.13/KWh of electricity consumed at the residential sector (https://www.dpdc.org.bd/index.php/customer-service/tariff-rates).

The economic analysis encompassing electricity sales, carbon credits, and the cost (capital and operating) of MSW incineration and LFG gas recovery WtE strategies is shown in Fig. 9. Higher electricity production from MSW incineration increases the revenue as result of higher sales of electricity and associated claiming of carbon credits due to higher avoidance of $CO_2$ from coal based power plant. Approximately US $ 535 million and US $ 251 million of revenue can be generated from the sales of electricity and claiming of carbon credits from MSW incineration and LFG recovery, respectively in Dhaka and Chittagong city under the CAGR approach of MSW projection. While under the historical MSW rate based MSW projection resulted into US $ 412 million and US $ 188.92 million of revenue. However, incineration requires higher capital and operating costs than LFG recovery system.

### 4.4. Scenario analysis

#### 4.4.1. Energy potential and net GHG

Impacts of MSW to energy conversion and associated GHG emissions were evaluated using six scenarios with varying WtE generation strategies (Table 8) for Dhaka and Chittagong city for the same reason mentioned in the Section 4.3. Potential energy and net GHG emissions under different scenario is presented in Fig. 10. BaU scenario is the worst one as expected, because of highest net GHG emission. The net GHG emission for all scenarios range from −0.29 to 0.81 t $CO_2$ e/t

MSW. The negative value in net GHG emission represents, this respective strategy avoids more $CO_2$ than its process emission. Five alternative scenarios for MSW to energy generation are evaluated in this study. The results show that, MSW incineration has higher energy potential with even negative net GHG emission, means this WtE option avoid more $CO_2$ because of higher replacement of electricity produced from coal based power plant. Based on this study, scenario $A_1$ generates 0.37 MWh/t MSW of electricity with −0.29 t $CO_2$e /t MSW of net GHG emissions. 0.27 MWh/t MSW of electricity generation and a moderate rate of net carbon emission (0.17 t CO2/t MSW) is for scenario $A_3$. Comparatively better performance (0.31 MWh/t MSW of electricity and −0.01 t $CO_2$e /t MSW of net GHG emissions) is also observed in scenario $A_4$- a strategy with MSW incineration key component (70% MSW incineration and 30% LFG recovery system) than $A_2$, $A_3$, and $A_5$ scenario.

#### 4.4.2. Profitability assessment

Under Scenario $A_0$ (BaU) no energy recovery is considered based on the existing MSW management system in Dhaka and Chittagong city. Hence, current costs for managing (collection to disposal) the MSW represent the operating costs. Existing operating costs for the MSW management practices is approximately BDT. 626.24 ($ 7.97)/ton MSW in Dhaka [1], while in Chittagong it is BDT. 439 ($ 5.59)/ton MSW [32]. Operating cost of Scenario $A_0$ represent addition of these two costs.

The cost and profit analysis of different scenario is presented in Fig. 11. Since, no effort is currently going on in both cities to recover energy or generation of revenue from MSW, BaU scenario resulted into negative net profit as expected. Highest profit (US $ 16.73/ton MSW) observed for Scenario $A_1$. This Scenario can be considered as the optimal scenario because of comparative advantage of highest energy potential, profitability and climate benefit in terms of GHG emission reduction.

**Table 8**
Scenario description for the WtE option in Dhaka and Chittagong, Bangladesh.

| Scenario | Description |
| --- | --- |
| Scenario $A_0$ | Business as usual (BaU) scenario representing no WtE implementation. |
| Scenario $A_1$ | All the MSW will be incinerated to generate electricity under the WtE project. |
| Scenario $A_2$ | All the MSW will be landfilled to generate electricity from LFG, under the WtE project. |
| Scenario $A_3$ | 50% MSW will be incinerated and 50% MSW will be utilized through LFG recovery system for integration of WtE (landfill and incineration) strategy. |
| Scenario $A_4$ | 70% MSW will be incinerated and 30% MSW will be utilized through LFG recovery system for integration of WtE (landfill and incineration) strategy. |
| Scenario $A_5$ | 30% MSW will be incinerated and 70% MSW will be utilized through LFG recovery system for integration of WtE (landfill and incineration) strategy. |

## 4.5. Sensitivity analysis

Energy potential and GHG emissions variation is evaluated through a sensitivity analysis by varying the moisture content of MSW within the range of ± 0 to 30%. Sensitivity analysis is performed only for scenario $A_1$ because it is identified as best WtE strategy for the management of MSW in Bangladesh based on the scenario analysis. Fig. 12 presents the sensitivity analysis results. Based on the sensitivity analysis, it can be say that moisture content of MSW has considerable effects on the overall GHG emission and energy generation. The increase or decrease of moisture content can alter inversely the energy content, electricity generation, and GHG emissions with a magnitude of 2%, 4.3%, and 9.5%, respectively. Reduction of moisture content therefore can have positive impacts, and pre-heating of MSW is suggested to increase the energy potential and reduced GHG emissions in Bangladesh.

## 5. Conclusion

Management of urban waste is one of the mitigation program to reduce the GHG emissions as mentioned in the Bangladesh Climate Change Strategy and Action Plan (BCCSAP). Moreover 2008 Renewable Energy Policy of Bangladesh also set a target to deliver 5% of energy from renewable sources by 2015, and 10% by 2020. On the other hand, the INDC of Bangladesh mentioned about the adoption of waste biomass-based thermal energy generation and promotion of landfill gas capture and power generation. In view of the mentioned contexts, this study is an attempt to inform the policy maker of Bangladesh regarding the potentiality of MSW as renewable source of energy and associated climate benefits in terms of GHG emissions reduction. Ever growing shortage of available land space and increasing demand for energy have necessitated the development of a national WtE strategy. Energy security issue is one of the four security issues

addressed in "National Adaptation Action Plan to climate change (NAPA)−2009" [73]. Yet the country is still not stepping forward to expand the renewable energy generation strategy, and still relying on fossil fuel resources. As mentioned earlier, there is a modest target to generate 5% and 10% of electricity from renewable sources by 2015 and 2020, respectively [74]. This policy should be reform considering the Bangladesh commitment towards low carbon economic development as manifested in many national documents like 7th five year plan. This study feels also the urgency of reforming the renewable energy generation policy based on the MSW to renewable electricity generation because today or tomorrow, developing countries like Bangladesh will be also under the strict regulation for carbon emission reduction, due to uncertainty regarding climate sensitivity [75].

Based on waste characteristics, population growth and waste generation rates in the major city corporation areas, 308 municipalities and 208 other urban areas of Bangladesh, MSW and associated GHG emissions is projected. In order to show the MSW renewable energy generation potential and associated climate benefits in terms of GHG emissions reduction two selected WtE technology, such as- MSW incineration and LFG recovery is evaluated in this study. Recognized energy conversion models and carbon emission models were used to perform the WtE analysis focusing on potential renewable electricity generation, climate benefits in terms of GHG emissions reduction, and economic benefits. Six alternative scenarios for WtE were assessed. Scenario $A_1$ which comprises incineration of mixed MSW provides the highest net profit with better energy potential and net GHG emissions reduction. The total estimated economic profit in 2050 could be US$ 170.76 million, and US$ 128.87 million, respectively under the CAGR approach and historical rate of MSW projection for scenario $A_1$. The estimated economic profit US$ 170.76 million is about 10 times higher than the income US$ 16.45 million during 2014 of Chittagong city corporation [4,76] and about 4 times higher than the income US$ 40.82 million during 2013 of Dhaka south city corporation (DSCC)
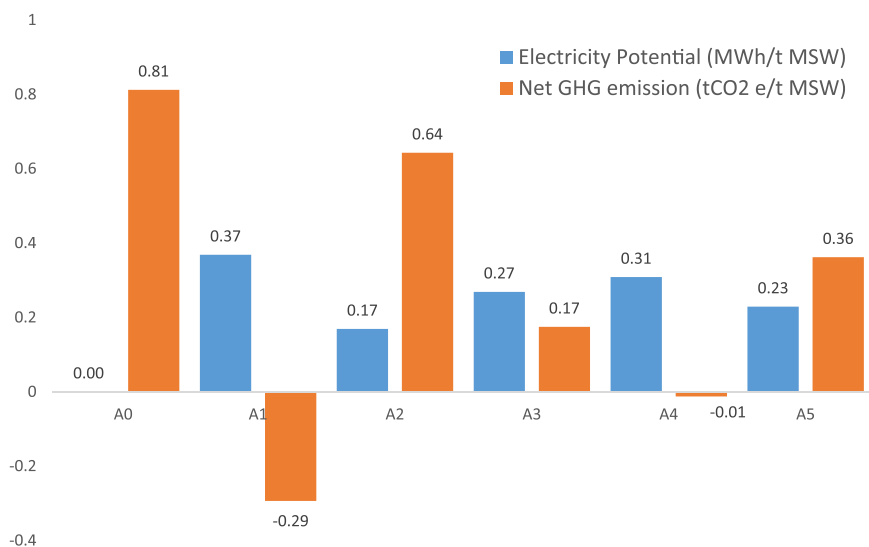


**Fig. 10.** Energy potential and net GHG emissions of different WtE scenarios in Dhaka and Chittagong city, Bangladesh.
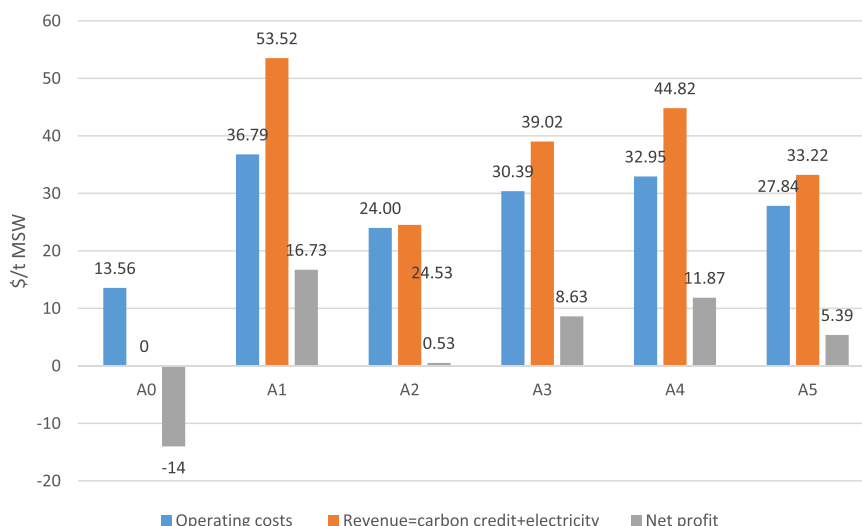
**Fig. 11.** Costs and profit analysis of different WtE scenarios in Dhaka and Chittagong city, Bangladesh.
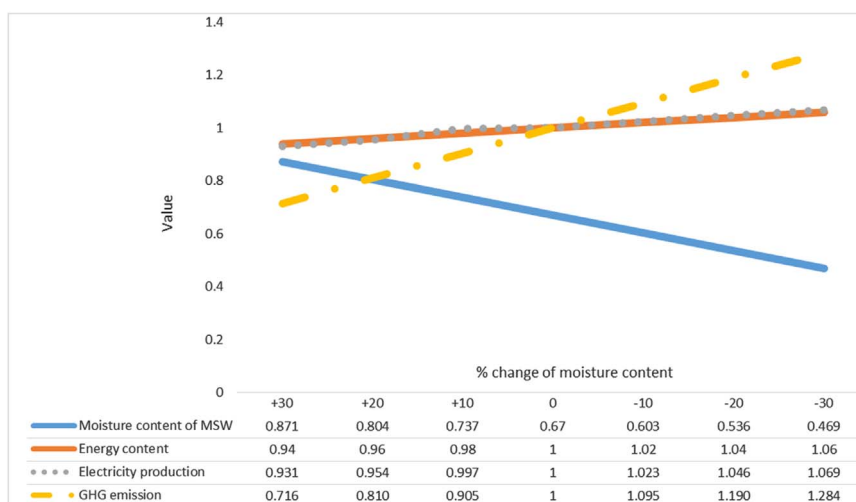


| % change of moisture content | +30 | +20 | +10 | 0 | -10 | -20 | -30 |
|---|---|---|---|---|---|---|---|
| Moisture content of MSW | 0.871 | 0.804 | 0.737 | 0.67 | 0.603 | 0.536 | 0.469 |
| Energy content | 0.94 | 0.96 | 0.98 | 1 | 1.02 | 1.04 | 1.06 |
| Electricity production | 0.931 | 0.954 | 0.997 | 1 | 1.023 | 1.046 | 1.069 |
| GHG emission | 0.716 | 0.810 | 0.905 | 1 | 1.095 | 1.190 | 1.284 |

**Fig. 12.** Sensitivity analysis of MSW moisture contents on WtE performance and GHG emission.

[77]. Through the scenario analysis the prospects of WtE strategy has validated in Bangladesh to mitigate the GHG emissions and to generate considerable revenue from electricity sales and carbon credit [4].

Pre-heating of MSW to reduce moisture can boost the energy recovery as well as GHG emission reduction. To initiate nationwide circular economy principles and industrial ecology concepts this study feels the urgency of adopting national WtE strategy to generate renewable electricity from MSW in Bangladesh. This study reveals that, the nationwide WtE strategy will ensure availability of cheaper and greener energy to reduce the energy crisis problem to a certain extent, and resolve the existing MSW management crisis to a greater extent. So, the study concludes that, renewable electricity generation policy based on WtE strategy using mixed MSW incineration will deliver climate benefits nationally and globally, and will ensure climate friendly urban area management in Bangladesh.

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